Appendix F
Fluvial Geomorphology

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Appendix F
Fluvial Geomorphology

Ultimately, the Aquatic Habitat Guidelines program intends to offer one complete set of appendices that apply to all guidelines in the series. Until then, readers should be aware that the appendices in this guideline may be revised and expanded over time.

Fluvial geomorphology is the study of landform evolution related to rivers. Although most streambank-protection projects do not require an intensive, watershed-scale, geomorphic analysis of the project reach, any project that potentially affects natural river processes will require a basic understanding of the fluvial geomorphology of the system in question.

BASIC CONCEPTS IN FLUVIAL GEOMORPHOLOGY

Scale

The variables affecting stream systems, such as climate, geology, vegetation, valley dimensions, hydrology, channel morphology and sediment load, have different causal relationships with one another, depending upon the time scale of analysis.[1] Over thousands of years, climate and geology have driven all other variables. Climate change is one of the most obvious and ongoing types of disturbance mechanisms affecting stream channels. However, it is a complex phenomenon and cannot be accurately assessed over a short period of time. Over short time scales (one to 10 years), most variables become independent. Discharge and sediment load become the only dependent variables.[2] At this scale, some disturbances caused by human activities can be assessed. For example, overgrazing can affect hydrology and sediment load, potentially causing channel erosion and incision. Defining the temporal scale of observation, therefore, is key for assessing relationships between various attributes of fluvial systems.

Equilibrium

A basic concept in fluvial geomorphology is that stream channels tend toward an equilibrium state in which the input of mass and energy to a specific system equals the outputs from the same system.[3] A corollary to this condition is that the internal forms of the system (such as channel morphology) do not change in the transfer of mass and energy. The term "stream-channel equilibrium" refers to the relative stability of the channel system and its ability to maintain its morphological characteristics over some period of time and range of flow conditions. In reality, perfect equilibrium does not exist in natural streams. However, natural streams do tend to develop channel sizes and shapes that accommodate their own typical discharge levels and character and quantity of sediment supplied by the watershed. These streams are said to be in a state of approximate equilibrium.[3,4]

Streams respond to minor system alterations (such as a change in hydrologic regime due to human activity) by modifying their size, shape and profile. Geomorphologists describe two altered states of equilibrium that account for this temporary instability in a channel system.[3,5]

1. *Steady-state equilibrium* occurs when short-term fluctuations in a given variable occur throughout the channel system; but the longer-term, constant mean value of the variable is maintained. An example of steady-state equilibrium occurs when channels adjust to scour and fill associated with seasonal flooding. It is important to note that the time scale of observations is critical for defining an equilibrium state - if the time scale is too short, the mean value of the variable in flux will not be accurately determined.

2. *Dynamic equilibrium* occurs when short-term fluctuations in a given variable occur around a longer-term mean value that is also changing. An example of dynamic equilibrium occurs when a stream adjusts to a slow change in base level (the level below which a stream cannot erode - the ultimate base level being sea level). In this instance, the stream undergoes a complex pattern of erosion, deposition, changes in sediment load and renewed incision as it adjusts to the new base level.

Regime Theory and Channel Geometry

Prior to extensive use of equilibrium principles by geomorphologists, hydraulics engineers used the concepts of equilibrium in *regime theory*.[3] Regime theory is based on the tendency of a stream system to obtain an equilibrium state under constant environmental conditions. It consists of a set of empirical equations relating channel shape to discharge, sediment load and bank resistance. The theory proposes that dominant channel characteristics remain stable for a period of years and that any change in the hydrologic or sediment regime leads to a quantifiable channel response (such as erosion or deposition). Stream reaches that are "in regime" are able to move their sediment load through the system without net erosion or deposition and do not change their average shape and dimensions over a short time period.[6] By definition, regime theory is not applicable to streams located in landscape positions where overall erosion and deposition is the natural process (such as alluvial fans, deltas, or headwater source areas).

Regime theory formed the basis for a large body of work in fluvial geomorphology focusing on identifying and defining the geometric properties of equilibrium alluvial channels and their adjustments to discharge and sediment transport regimes.[7] According to R. D. Hey,[6] the nine measurable variables used to define equilibrium channel geometry are:

1. average bankfull channel width (w),
2. average bankfull depth (d),
3. maximum depth (d_m),
4. velocity (V),
5. height (Δ) of bedforms,
6. wavelength (λ) of bedforms,
7. slope (S),
8. meander arc length (z), and
9. sinuosity (*P*).

These characteristics may be considered dependent variables for stream reaches that are in regime.

The six independent variables that control changes in channel dimension and shape are:

1. discharge (Q),
2. sediment load (Q_s),
3. size of bed material (D),
4. bank material,
5. bank and floodplain vegetation (riparian and/or upland species), and
6. valley slope (S_v).

With the exception of discharge, vegetation and bed-material transport (which may vary over time), the independent variables remain constant when a stream channel is in regime. Changes in any of these independent variables may result in a new channel geometry that represents a stable morphology in a new equilibrium state.

Geomorphic Thresholds

Short-lived states of disequilibrium often result when a geomorphic threshold is exceeded. A geomorphic threshold, as defined by S. A. Schumm,[5] is "a threshold of landform stability that is exceeded by intrinsic change of the landscape itself, or by a progressive change of an external variable." The classic example of a geomorphic threshold is the attainment of critical shear stress in a channel during increasing discharge. When critical shear is exceeded, sediment motion is initiated and sediment transport ensues.

Both extrinsic and intrinsic geomorphic thresholds exist. An extrinsic threshold is exceeded by application of an external force or process, such as a change in sediment supply or discharge. Progressive change in the external force triggers an abrupt, physical change in the system. Examples of forces relating to extrinsic thresholds are climatic fluctuations, land-use changes and base-level changes. An intrinsic threshold is exceeded when system change occurs without a change in an external variable; the capacity for change is intrinsic within the system and can be considered the system's natural variability. An intrinsic threshold might be reached when a torturous meander bend becomes unstable, resulting in a meander cutoff and subsequent reduction in sinuosity.[8]

The most significant controls on channel stability over a period of years or decades are flow regime vegetation and sediment supply. If any of these controls changes (either progressively or suddenly), the channel may cross a threshold and undergo change. Channel avulsion, the formation of a new channel across the floodplain and channel degradation, the general lowering of channel-bed elevation, are two common types of channel changes involving geomorphic thresholds.

Channel avulsion and degradation/incision are not the only ways in which streams respond to the unique combination of drivers and controls acting upon them. On the horizontal plane there is lateral migration (meandering), channel widening, channel narrowing and avulsion. On the vertical plane, rivers incise and aggrade.

Channel Avulsion

Channel avulsion is a common response occurring when a stream has reached a geomorphic threshold. An avulsion is a major change in channel direction, location or form, usually initiated by a large flood. Avulsions often result from scour and headcutting into the floodplain. They occur in numerous types of channels. Anastomosing channels, which have multiple, active threads, cohesive banks and low migration rates, tend to avulse as the channel threads age and lose transport efficiency. Braided channels, which have high sediment loads, may avulse under two conditions:

1. as backwater conditions occur upstream from a constriction (e.g., aggrading bar or bridge), an overflow may occur (often on the outside of a bend); or
2. as overflow into a side channel or abandoned oxbow occurs, headward erosion and stream capture may develop.[9]

Meandering channels may avulse due to insufficient sediment transport, which results in channel aggradation and further loss of channel capacity. Aggradation increases the frequency of overbank flows and avulsion potential. Topographic variability on the floodplain surface can also concentrate overbank flows in certain areas and create further avulsion potential. Avulsion potential is also increased if floodplain roughness is relatively low compared to the active channel roughness, which is common in areas where the floodplains have been cleared for agriculture. Finally, all channels are prone to avulsion if they become perched relative to their floodplain. This is common in alluvial-fan environments or along relocated channel segments.

Channel Degradation

Degraded channels (also called entrenched, eroded, or incised channels) occur when sediment-transport capacity exceeds sediment supply, causing a lowering of the channel bed. Stream channelization, land use that increases runoff or concentrate high flows, or a lowering of base level are all potential causes of channel degradation. The process of degradation often begins when channel stability reaches a threshold condition; the threshold is then crossed, and bed degradation occurs, often followed by channel widening as streambanks erode.[10]

Because the response pattern of incised channels is remarkably similar throughout a variety of stream environments, incised-channel evolution models are useful for tracking land-form development through time. S. A. Schumm, et al., used such a model to develop a channel-evolution sequence for a stream in Mississippi.[11] The model assumed that the base level for the channel did not change and that land use in the watershed remained relatively constant. The model (see *Figure F-1*) described five channel reach types (Types I to V) whose conditions ranged from disequilibrium (Type I) to a new, dynamic equilibrium (Type V).[10]

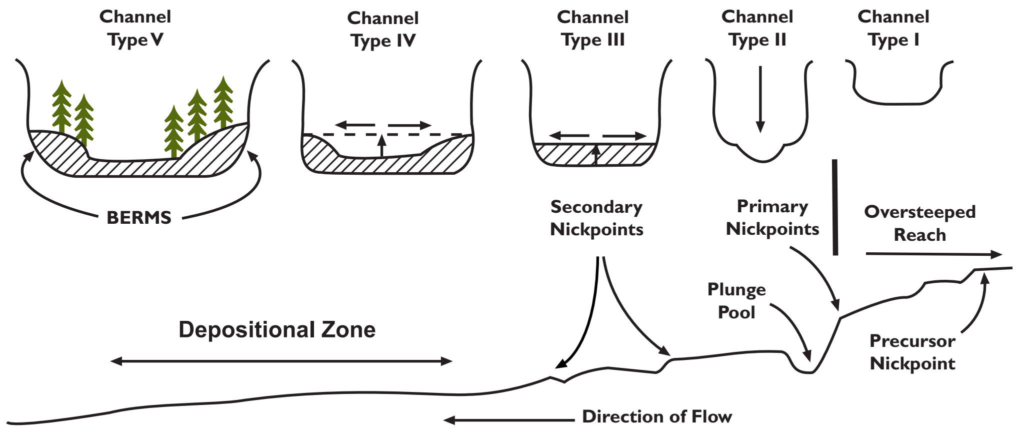

Figure F-1. Diagram of a channel evolution model.[10]

SEDIMENT-TRANSPORT PROCESSES

The sediment-transport process begins with the erosion of soil and rock in a watershed and transport of that material by surface runoff. The transport of sediment through a river system to the ocean or closed basin consists of multiple erosional and depositional cycles, as well as progressive physical breakdown of the material. Many sediment particles are intermittently stored in alluvial deposits along the channel margin or floodplain and ultimately re-entrained via bank and bed erosion. Total sediment loads consist of suspended load (the fine-grained fraction transported in the water column) and bedload (the coarse-grained fraction transported along the channel bed). The transport of sediment through the stream system depends on the sediment supply (size and quantity) and the ability of the stream to transport that sediment supply.

Sediment-Transport Processes and Aquatic Habitat

The caliber, volume and transport dynamics of sediment exerts a major control on channel form and geomorphic processes that create and sustain aquatic habitat in all river systems. Sediment caliber dictates what geomorphic features and associated habitat types (e.g., sand bed vs. gravel bed) will be characteristic of a given channel. Sediment volume can affect the stability of a channel, causing channel aggradation if the volume delivered is in excess of the transport energy available and causing channel degradation if the volume is insufficient. Sediment volume may also affect channel pattern and slope, with high volumes of coarse sediment resulting in relatively steep slopes, high width/depth ratios and braided channel patterns.[5]

Some degree of sediment mobility is critical for the ecological health of a stream system. Most Pacific Northwest aquatic organisms have evolved within dynamic stream systems, in which pools, bars and other habitat features are continually reworked and reformed. Physical habitat is created and sustained through processes such as the maintenance of pools and riffles, the formation of transient bars, side channels, and backwater areas, the deposition of spawning gravels, and the flushing of fines from bed substrate.

Sediment sorting through selective transport creates spawning habitat and quality habitat for benthic organisms, which in turn are food for aquatic species such as fish. The maintenance of pool-riffle sequence morphologies and the effective sorting of bed materials exemplify balanced conditions of sediment caliber and transport energy that serve to generate and maintain quality aquatic habitat.

Stream Features Maintained by Sediment Transport

Riffle-Pool Sequences

Riffles and pools are often the dominant bedforms in coarse-grained channels. In alluvial channels, pools are created by erosional processes on the outer part of river bends and below instream obstructions. Riffles are associated with straighter, often higher-gradient areas and are characterized by shallow, faster flow. Pools tend to scour at high flow and fill at low flow, whereas riffles may scour at low flow and fill at high flow.

Channel Bars

In both meandering and braided streams, channel bars are ubiquitous features representing sediment deposition and storage in the channel. Bar formation is a result of local reductions in sediment transport capacity. Bars are present in steambeds composed of silt, sand, gravel and cobble, and they occur on the inside of bends (point bars), along channel margins and within the active channel flow. Channel bar terminology includes a substantial and inconsistent array of names that has not yet been standardized in the literature. Channel bars that divide channels and divert flow are responsible for the initiation and maintenance of the braided channel pattern. Channel bars represent temporary sediment storage in the stream channel. Channel bars also represent the incipient floodplain that may become established if additional sediment is deposited on the bar and vegetation takes hold.

VEGETATION AND WOODY DEBRIS

Both upland and riparian vegetation affect the geomorphology of stream channels. Vegetation plays a key role in stabilizing streambanks dissipating energy and in maintaining a stable channel form. The growth of riparian vegetation in or near the channel augments floodplain formation as vegetation increases hydraulic roughness reduces erosion and promotes sedimentation. Upland vegetation slows hillslope erosion, and both upland and riparian vegetation contribute woody debris to the stream system. The role of large woody debris in channels is now recognized as a critical factor affecting geomorphology in forested environments and as a potential component of channel design.[12,13]

Coarse or large woody debris in streams represents large roughness elements that divert flowing water and influence the scour and deposition of sediment in forested streams throughout the world. Large woody debris in stream channels results from trees that fall on banks or hillslopes. Processes that initiate tree fall include windthrow, bank erosion, channel avulsion, tree mortality, mass wasting and land-use practices such as logging.[14] The introduction of large woody debris into the channel affects both channel form and process by:

- creating steps in the longitudinal profile of the streambed, thus dissipating energy aiding in formation of both pools and riffles and increasing sediment storage;[14]
- improving fish habitat by increasing types and sizes of pools[15] (pools associated with woody debris may be deeper and have more depth variability than free-formed pools[16]);
- forming channel bars[17] and creating suitable sites for spawning (this influence has not been extensively studied); and
- promoting sediment deposition along the active channel and floodplain, which provides sites for riparian-vegetation colonization, the growth of forested islands in the channel and forest floodplain development.[18]

Overall, the geomorphic effects of woody debris vary with stream size. In low-order streams (first and second order), woody-debris elements are large relative to the stream and may cause significant channel migration or widening and sediment storage. In high-order streams (fifth order), where woody-debris elements are small relative to the channel, woody-debris accumulations may increase channel migration and the development of secondary channels,[14] although islands formed as a result of large woody debris may actually increase stability.[16]

A bibliography of literature addressing the role of wood in aquatic systems and riparian areas has been assembled by researchers in the United States, United Kingdom and Russia. It is available on-line at http://riverwood.orst.edu/html/intro.html.

ASSESSMENT METHODOLOGIES

Baseline Geomorphic Analysis: Evaluation of Existing Conditions and Historic Change Where Restoring Historic Configuration is Appropriate

The most important components of geomorphic analysis include:

- assessment of past channel change,
- determination of causes of channel change, and
- assessment of ongoing channel adjustments.

Streambank protection will likely be unsuccessful if the driving forces of channel adjustments are not recognized and addressed. Consequently, streambank-protection projects designed to mimic or alter natural channel processes require an understanding of the causative agents of change.

Characterizing Existing Channel Conditions

The initial characterization of the project reach should be based on plotted bed and bank profiles and maps or aerial photographs that show channel planform. The project reach should be described in terms of channel slope, pattern, sinuosity and access to its floodplain. Infrastructure controls should be identified and their geomorphic relevance indicated, such as fixed-bed elevations (pipelines, weirs, bridge aprons) or channel or floodplain encroachment (roads, culverts, development, bridges).

Channel Slope

Channel slope is defined as the vertical fall of a stream over a given distance. It is typically reported as a percentage (ft/ft) or as feet of drop per mile (ft/mile). Channel profiles (elevation vs. distance plots) depict slope trends on a stream system. The most accurate means of determining the slope of the channel bed is by surveying the channel thalweg elevation (the deepest point in the channel bed) over a given distance. Alternatively, longitudinal profiles may be obtained from the Federal Emergency Management Agency if a hydraulic model has been developed for flood-insurance studies. Channel profiles determined from topographic maps may be accurate in some situations, but may not be detailed enough, since contour lines generally reflect the water surface rather than the channel bed and, for smaller streams, may actually represent the canopy cover.

Channel slope is always measured in terms of the channel distance, rather than the valley distance, and can be calculated by the following equation:

$$S=(E_2-E_1)/D$$

Where: S = *channel slope*
E_2 *and* E_1 = *channel-bed elevations at two points along the thalweg*
D = *channel distance between* E_2 *and* E_1.

A more accurate representation of channel slope will be attained if survey points are located from the top of one riffle to the top of another riffle (thereby including the entire channel unit), rather than between a riffle and a pool. The longer the survey length, the more accurate the slope calculation, unless a significant valley control is crossed.

Channel Planform

Channel planform is the condition of a stream as seen in map (aerial) view. In streams with meandering patterns, planform is quantitatively described in terms of sinuosity by the equations:

$P=D_c/D_v$ *or*
$P=S_c/S_v$

Where: P = *sinuosity*
D_c = *channel length*
D_v = *valley length,*
S_c = *channel slope*
S_v = *valley slope.*
Channel length is measured along the channel thalweg or, if necessary, the channel centerline.

Other parameters that describe channel planform are the wavelength, amplitude, belt width, bankfull width and radius of curvature of an individual meander bend (*Figure F-2*). Collectively, these planform characteristics can be compared to historical conditions in order to assess channel behavior over time.

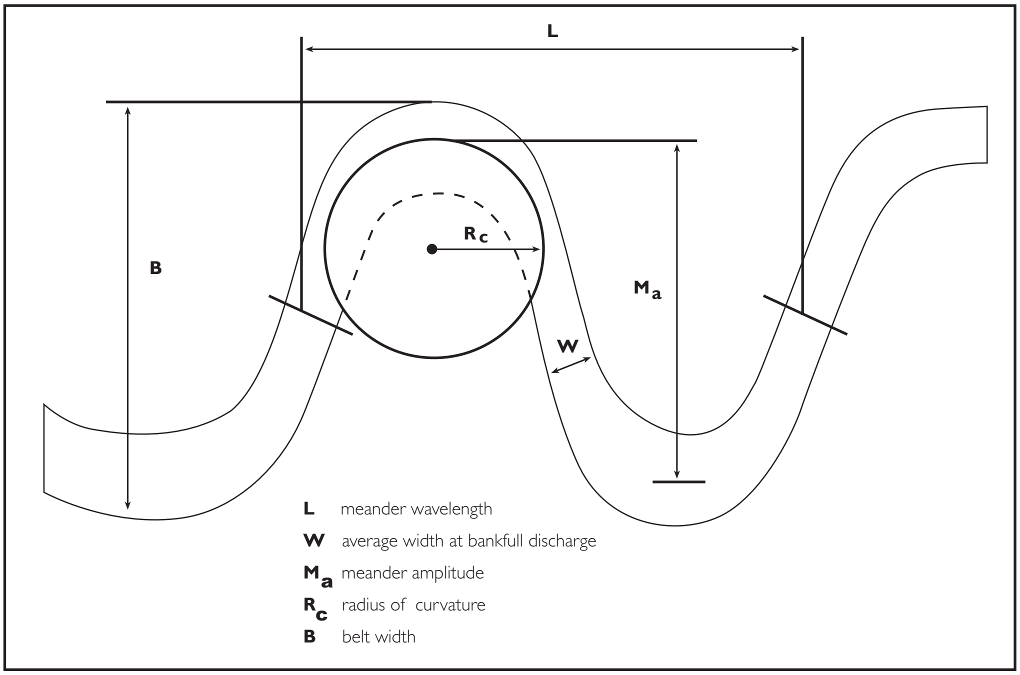

Figure F-2. Channel planform characteristics.

Channel Cross Section

Channel cross section reflects the two-dimensional view of the channel, typically viewed in the downstream direction (*Figure F-3*). Points collected from a surveyed cross section should at a minimum contain floodplain elevation, top of bank, bank toe, bankfull depth lower limit of vegetation, water surface elevation and thalweg. Typical dimensions measured from a channel cross section include top and bankfull width, bank height, bank slope and channel depth. By convention, the right and left banks reflect the sides of the channel as viewed in the downstream direction.

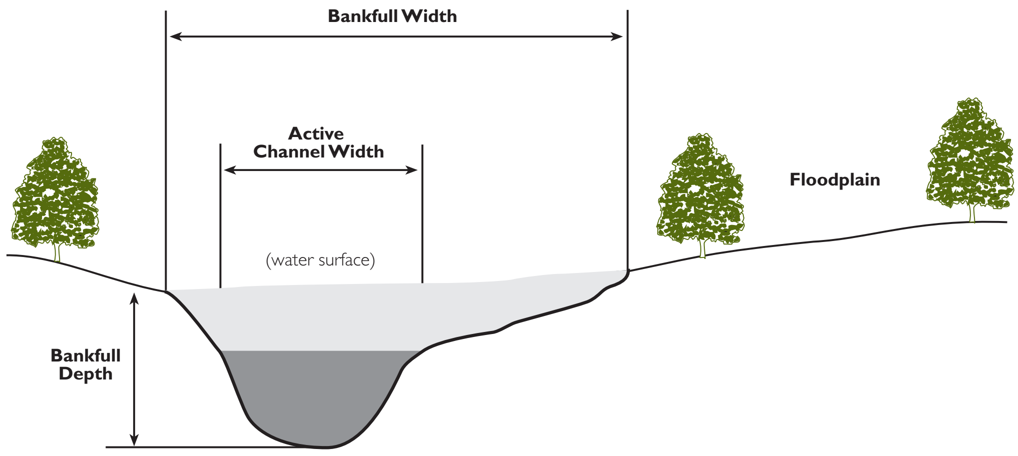

Figure F-3. Channel cross section.

Pools and Riffles

Pools and riffles generally occur at relatively constant spacing in alluvial streams. A pool-riffle sequence is a dynamic response of the channel to a large-scale, nonuniform distribution of three variables: velocity, boundary shear stress and sediment.[19] L. B. Leopold, et al., determined that riffle spacings were consistently on the order of five to seven times the channel width (*Figure F-4*).[4] This empirical deduction is consistent with a theoretically predicted spacing of 2π (6.28) times the channel width determined by R. D. Hey.[20] Hey and C. R. Thorne further substantiated the correlation between width and riffle spacing, predicting riffle spacing as:

$$z = 6.31w$$

where z = the distance of riffle spacing, and
w = bankfull width.[21]

This definition of riffle spacing is based on work in Great Britain on gravel-bed rivers with single-thread channels and a mix of straight, sinuous, and meandering planforms. The coefficient of determination for this data set is 0.88, and the overall range of riffle spacing for the majority of sites is between four and ten times the channel width. The original assertion for riffle spacing made by Leopold, et al., then, still hold after almost forty years of observation and measurement.[4] Hey and Thorne's prediction[21] may be more site-specific and, therefore, not universally applicable to alluvial streams found in various landscapes and climate zones.

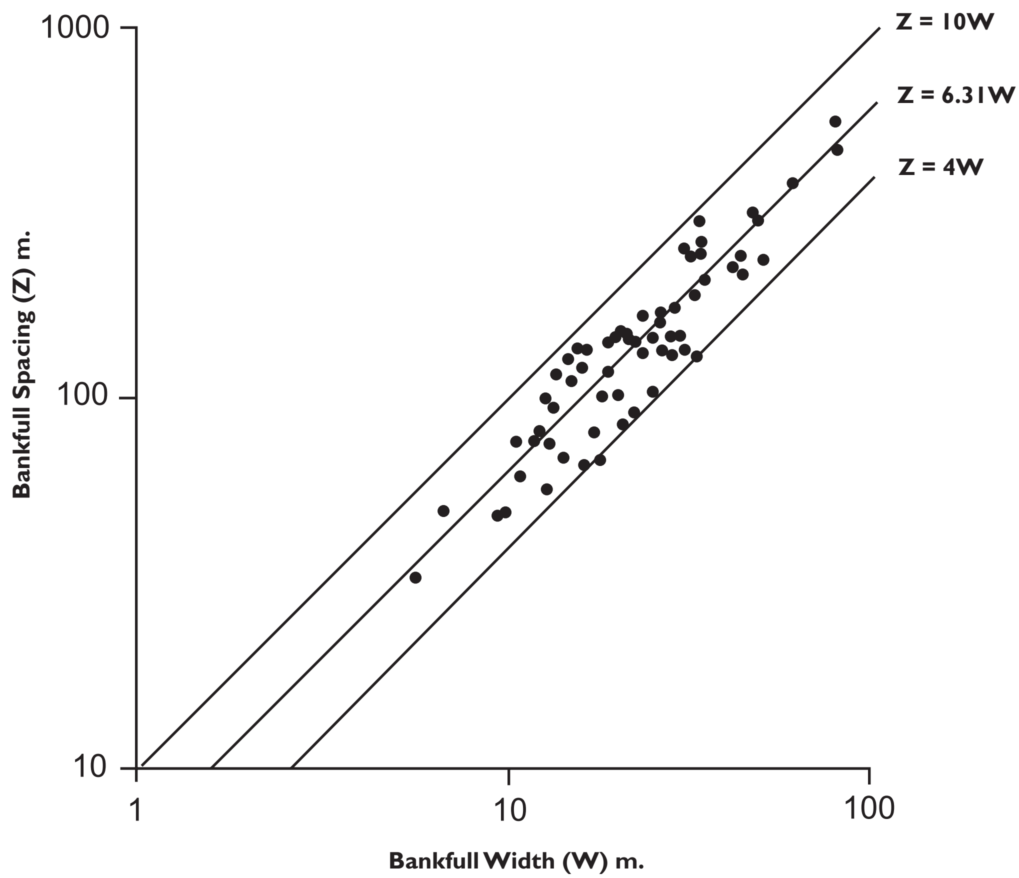

Figure F-4. Riffle spacing as a function of bankfull width.

Channel Classification

A classification of subreaches can aid in visualizing and describing the project site, although classifications on their own provide limited application for channel restoration designs.[19] Early classification systems were based on channel planform patterns (e.g., those developed by Leopold and M. G. Wolman[22]), including meandering, braided and straight channel patterns. Later classification systems were also based on channel cross-sectional geometry, longitudinal profile, patterns and size/composition of bed material (e.g., those developed by D. L. Rosgen[23]). Other recent classifications attempt to link channel process, form and stability.[24,25,26] Finally, D. R. Montgomery and J. M. Buffington's classification[27] is based on a hierarchy of spatial scales that reflect different geomorphic processes and controls on channel morphology. This system (which includes geomorphic provinces, watersheds, valley segments, channel reaches and channel units) provides a useful means for comparing channels at increasingly finer spatial scales.

Rosgen's classification system[23] is the most extensive and widely applied. This system divides streams into eight major types based on number of active channels, presence of a floodplain, width/depth ratio and sinuosity. Each major type is then subdivided, based on the channel slope and dominant type of bed and bank materials. To date, this system for stream classification is probably the most comprehensive and useful, provided that practitioners have a strong geomorphological background.

It is important to note that most classification systems are based on the existing channel morphology of a stream in dynamic equilibrium, a rare occurrence especially in disturbed or urban watersheds. Therefore, a classification system must be used with the understanding that fluvial systems are constantly adjusting and evolving in response to changes in slope, hydrology, land use and sediment supply. Furthermore, classification systems are rarely appropriate as the basis for a channel or streambank design.

Assessing Historic Channel Change

Aerial Photography

When available, sequential photos of a stream channel over the last 100 years provide a historical record of channel planform changes. This information, coupled with hydrologic data from stream gauges, is extremely valuable for understanding how the particular channel responds to floods. An evaluation of historic channel change may reveal previous channel conditions that provided quality habitat or channel stability, which may then be used as the basis for project objectives. However, an aerial photo provides a snapshot in time, and channel stability cannot be inferred from a photo. The stream may have been responding to significant changes in the watershed – there is no reason to assume that a past morphological form will be stable under current hydrologic and landscape conditions *unless* everything has stayed the same (not usually the case).

Aerial photographs for areas in the western United States are available beginning in the 1930s typically and are recorded in a database maintained by the U.S. Geological Survey Earth Science Information Center (the USGS will search for historical photography at ***1-888-ASK-USGS***). Access to maps produced by USGS can be found at www.usgs.com. Aerial photographs of your region can be obtained from the Washington State Department of Natural Resources, the Washington State Department of Transportation, the Federal Bureau of Land Management, the U.S. Forest Service, the U.S. Army Corps of Engineers and the Natural Resources Conservation Service.

Ground Reconnaissance

Field observations provide valuable information regarding flood history and channel response. This information is especially valuable when combined with hydrologic data regarding flood-recurrence intervals - for example, the effects of recent 10-year or 25-year recurrence-interval flows might be directly observed in the field. Primary flow direction can be significantly different for a two-year event versus a 10-year event. Ground assessment of stream channels may include observable flood impacts, such as abandoned channels, natural channel cutoffs or the accumulation of woody debris on mid-channel bars. Many geomorphic channel features can be roughly dated according to the age of riparian vegetation that is present. For example, an abandoned side channel with 10-year-old cottonwoods present may represent the impacts of a flood documented 10 to 11 years ago. Ground reconnaissance is an essential part of a geomorphic assessment and can provide useful information on the geomorphic effects of large flows in a particular channel reach.

Application of Results

For pristine streams degraded by low-probability floods, the data retrieved from the historic baseline survey can provide a basis to restore the channel to its historic configuration. This process includes recreating channel conditions characteristic of preflood conditions in order to improve habitat conditions and promote geomorphic function. For streams impacted by long-term changes in hydrologic or sediment transport conditions (e.g., downstream of a dam or in an urbanizing watershed), restoration to a historic configuration may not be appropriate.

Advanced Geomorphic Analysis: Achieving Geomorphic Stability Where Historic Configuration is Inappropriate

Alluvial streams are highly dynamic and responsive to changes in hydrology, slope or sediment load. Historically, engineering projects have dramatically destabilized stream channels by imposing unnatural and inappropriate channel cross sections, slopes, discharges and sediment-transport regimes. The destabilization of streams occurs when the balance between transport energy and sediment supply is altered. If a project is designed to modify hydrologic or hydraulic regimes, sediment-transport continuity should be a primary project objective.

Geomorphic stability occurs when the channel is adjusted to convey flow and sediment without undergoing net erosion or deposition. Successful bank-protection projects promote that balance and provide for optimal channel function and aquatic habitat. One of the most significant challenges in streambank-protection projects is defining this state of channel equilibrium and directing the project to promote long-term channel stability. In the context of geomorphology, this assessment requires an evaluation of current channel conditions, an assessment of historic changes that may have resulted in channel destabilization, a determination of the mechanism and causes of destabilization and an estimation of conditions required to promote sediment-transport continuity.

Channel Stability

The assessment of channel stability relates the current sediment-transport capacity of the channel to the existing sediment supply. Excessive transport capacity results in channel degradation, which is commonly indicated by geomorphic features such as headcuts (steep breaks in channel profile), human activities such as extensive channel armoring, or bank oversteepening and gravitational failure. Channel degradation can result in a floodplain surface becoming high enough above the channel that it is no longer inundated by the current hydrologic regime (see *Figure F-5*. The formation of such a perched floodplain, or terrace, disconnects that surface from the water table and affects the establishment and survival of riparian vegetation. Other effects include unstable banks due to:

- oversteepening, bank instability due to groundwater discharge;
- increased shear stress because of low-probability flows being contained within the channel within the channel; and
- loss of wetland/floodplain habitat and backwater areas.

Figure F-5. Channel Degradation. An example of channel instability in a degrading channel.

This process is often coupled with the progressive formation of a new floodplain surface within the incised channel. Excessive sediment supply is generally evidenced by aggradation such as pool infilling, loss of channel capacity, overbank deposition, channel widening and extensive channel-bar development. Sediment-transport evaluations, such as incipient motion and sediment-continuity modeling, assess the mobility of sediment in a given system and can analyze reach stability.

A geomorphic assessment of the reach where the streambank-protection project is intended will provide some understanding of the causes and effects of channel change through time. This assessment includes quantifying historic changes via repeat bed profiles, maps, as-built bridge-survey data and sequential aerial photographs. Potential causes for geomorphic channel change include alterations in hydrology or sediment load, the occurrence of large floods and human activities such as urbanization and channelization. After completing the geomorphic assessment, the next step is to estimate geomorphic parameters that will provide for channel stability under project conditions. These steps, in combination with hydraulic analyses, then lead to the definition of design elements such as channel slope, planform and cross-sectional geometry.

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Figure F-5. Source: Inter-Fluve, Inc.